Analysis of Activation - Induced and Post - Activation Undershoot ΔR2* and ΔR2 Magnitudes and Ratios at 1.5 Tesla using Synchronous Gradient-Echo and Spin-Echo (SGS) - EPI

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Introduction:

This study involves the use of a synchronous gradient - echo and spin-echo (SGS) - echo planar imaging (EPI) sequence (1) to analyze, on a voxel - wise basis, relative gradient-echo and spin-echo changes during activation and during the post - activation undershoot. Simultaneous collection of gradient-echo and spin-echo time series provides precise spatial and temporal registration not achievable using separate time series.

The questions addressed on a voxel-wise basis in this study include: What is the correlation between the signal change magnitude and post activation undershoot magnitude? What is the correlation between ΔR2* / ΔR2 ratios during activation and during the post - activation undershoot? What is the correlation between ΔR2* and ΔR2 ratios and magnitudes of each?

Methods:

SGS-EPI was performed using a local three axis gradient coil at 1.5T (GE Signa). Gradient-echo TE = 30 ms, and Spin-echo TE = 110 ms. TR = 1 sec. Two axial planes (voxel volume = 3.75 x 3.75 x 10 mm^3) were obtained: one containing visual cortex and one containing motor cortex. Subjects viewed a red 8 Hz flashing LED display (GRASS™ goggles), and performed bilateral finger tapping when the visual stimulus was on. Each time series was 64 sec. in duration. Stimulus timing was 20 sec. off, 20 sec. on, and 24 sec. off. The time between successive series was at least 2 minutes. Thirty time series were collected, spatially registered, and averaged. Correlation analysis was performed to determine regions of motor and visual activation. From these regions, voxel-wise analysis was carried out.

Results and Conclusions:

Figure 1 shows simultaneously-acquired ΔR2* and ΔR2 time series from the motor and visual cortex of one subject. $\Delta R2(*) = -\text{Ln}(S_{act} / S_{rest}) / TE$. Visual cortex shows a larger undershoot than motor cortex. While this is typical, undershoots are still observable in motor cortex.

Figure 2 is a set of scatter plots from voxels in visual cortex of both subjects, showing ΔR2 and ΔR2* during activation (x axis) and during the post-activation undershoot (y-axis). ΔR2(*) for both the increase and undershoot appear correlated.

Figure 3 is a set of scatter plots showing a comparison of activation - induced ΔR2* and ΔR2 with ΔR2*/ΔR2. The two plots show significantly different shapes. ΔR2* shows a monotonic correlation with ΔR2*/ΔR2 - suggesting that as ΔR2* increases (likely with higher blood volume per voxel), the average vessel radius increases. The cluster of voxels showing the highest ΔR2* shows a ΔR2*/ΔR2 ratio of only 3 to 5. Based on susceptibility contrast models (2-4), this ratio corresponds to a radius of about 10μm - neglecting intravascular perturbation effects. The largest fMRI signal changes are thought to arise from vessels larger than 100μm - which should correspond to a considerably higher ΔR2*/ΔR2 ratio. These results appear to indicate a significant contribution of red blood cell susceptibility perturbations - having a ΔR2*/ΔR2 ratio of about 1.5 (5) - which factor in to reduce ΔR2*/ΔR2 to the value measured.

The relationship between ΔR2*/ΔR2 and ΔR2 is not monotonic. The voxels showing the highest ΔR2 also show a ΔR2*/ΔR2 ratio of 3 to 5, which is a larger ratio than would corresponding to capillary effects. This also implies an intravascular (red blood cell) contribution to ΔR2.

Table 1 summarizes the results from visual and motor cortex voxels of each subject. The increase and undershoot ΔR2*/ΔR2 ratios are not significantly different.

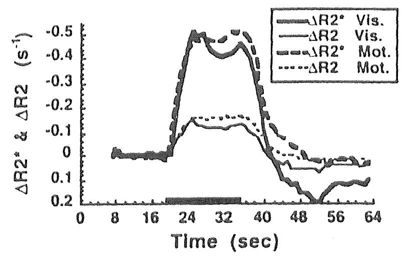
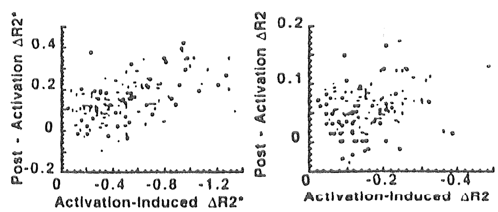
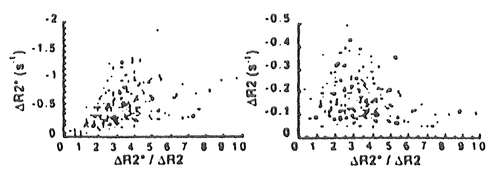


Figure 1: Simultaneously-acquired ΔR2* and ΔR2 time series from visual and motor cortex.



a. b.

Figure 2: Voxel - wise scatter plots of the relation between the activation - induced signal change and the post - activation undershoot **a.** ΔR2* and **b.** ΔR2.



a. b.

Figure 3: Voxel-wise scatter plots of the relation between ΔR2*/ΔR2 ratio and **a.** ΔR2* and **b.** ΔR2 magnitudes.

	ΔR2*	ΔR2	ΔR2*/ΔR2	i/u ΔR2*	i/u ΔR2
1 i V	-.58 ±.04	-.18±.01	3.32 ± .13	-3.6 ± .9	-3.0 ± .7
2 i V	-.45 ±.03	-.12±.01	4.13 ± .35	-3.1 ± .6	-2.4 ± .3
1 u V	.13 ± .01	.06 ± .01	2.31 ± .48		
2 u V	.15 ± .01	.05 ± 04	3.04 ± .46		
1 i M	-.55 ±.09	-.18 ±.02	3.39 ± .32	-5.8 ± 4.9	-4.1 ± .3
2 i M	-.51 ±.05	-.16 ±.01	3.15 ± .20	-2.4 ± 2.5	-2.6 ± 1.[illegible]
1 u M	.01 ± .02	.02 ± .01	1.48 ± .80		
2 u M	.01 ± .01	.02 ± .01	.83 ± .66		

Table 1: Left three columns: Relaxation rates and ratios from two subjects (1 and 2) and corresponding to the signal increase (i) and undershoot (u) in the visual (V) and motor (M) cortex. **Right two columns:** ΔR2* and ΔR2 increase to undershoot ratios.

References:

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